Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.14, n.2, e5639, 2019
Recife, PE, UFRPE. www.agraria.pro.br
DOI:10.5039/agraria.v14i2a5639
Protocolo 5639 - 13/01/2017 • Aprovado em 14/01/2019

# Drying kinetics of *Talinum triangulare* (Jacq.) Willd leaves and physicochemical assessment of flour

Ellen Carla Francisca Alexandre[1], Daniel Emanuel Cabral Oliveira[2], Osvaldo Resende[1], Marco Antônio Pereira da Silva[1], Carlos Frederico Souza Castro[1], Adriano Jakelaitis[1]

[1] Instituto Federal de Educação, Ciência e Tecnologia Goiano, Campus de Rio Verde, Rio Verde, GO, Brazil. E-mail: ellencarlabiologa@gmail.com (ORCID: 0000-0002-3946-5580); osvaldo.resende@ifgoiano.edu.br (ORCID: 0000-0001-5089-7846); marco.silva@ifgoiano.edu.br (ORCID: 0000-0002-3875-1104); carlos.castro@ifgoiano.edu.br (ORCID: 0000-0002-9273-7266); adriano.jakelaitis@ifgoiano.edu.br (ORCID: 0000-0003-0093-9846)
[2] Instituto Federal de Educação, Ciência e Tecnologia Goiano, Campus de Iporá, Iporá, GO, Brazil. E-mail: oliveira.d.e.c@gmail.com (ORCID: 0000-0002-3824-994X)

**ABSTRACT:** *Talinum triangulare* (Jacq.) Willd (Talinaceae) is a plant cultivated in Africa, Asia, and Latin America for medicinal and food purposes. This study aimed to assess the drying kinetics of *T. triangulare* leaves under different temperatures and the physicochemical characteristics of flour produced. Leaves were dried to constant weight in an oven at temperatures of 50, 60, 70 and 80 °C. Drying results were adjusted to mathematical models used to represent the drying of agricultural products. After drying, leaves were ground and the flour was analyzed for mineral and centesimal composition and scanning electron microscopy and absorption spectroscopy in the infrared region were performed. Page's model was the most appropriate for predicting the leaf drying phenomenon. The times required for drying were 32, 10, 7 and 6 hours at temperatures of 50, 60, 70 and 80 °C, respectively. Contents of N, Mg, and Cu in the flour samples were influenced by increasing drying temperature. Other variables of mineral, centesimal and structural composition were did not change. Due to the nutrient contents present in the leaves of *T. triangulare*, the flour produced can be used in new products.

**Key words:** mathematical modeling; medicinal plant; mineral composition; unconventional vegetables

# Cinética de secagem das folhas de *Talinum triangulare* (Jacq.) Willd e avaliação físico-química da farinha

**RESUMO:** *Talinum triangulare* (Jacq.) Willd (Talinaceae) é uma planta cultivada na África, Ásia e América Latina com fins medicinais e alimentares. Neste trabalho, objetivou-se avaliar a cinética de secagem das folhas de *T. triangulare* sob diferentes temperaturas e as características físico-químicas da farinha produzida. As folhas foram secas em estufa sob as temperaturas de 50, 60, 70 e 80ºC até atingirem massa constante. Os resultados de secagem foram ajustados a modelos matemáticos usados para representação da secagem de produtos agrícolas. Após secagem, as folhas foram trituradas e a farinha produzida foi analisada quanto à composição mineral e centesimal, microscopia eletrônica de varredura e espectroscopia de absorção na região do infravermelho. Dos modelos testados, o de Page foi o mais adequado para predizer o fenômeno de secagem das folhas. O tempo necessário de secagem foi de 32, 10, 7 e 6 horas para as temperaturas de 50, 60, 70 e 80 ºC, respectivamente. Nas farinhas, as concentrações de N, Mg e Cu foram influenciadas pelo aumento da temperatura de secagem. Outras variáveis de composição mineral, centesimal e estrutural não foram modificadas. Devido à concentração de nutrientes presentes nas folhas de *T. triangulare*, a farinha produzida pode ser utilizada ou incorporada em novos produtos.

**Palavras-chave:** modelagem matemática; planta medicinal; composição mineral; hortaliça não convencional

## Introduction

*Talinum triangulare* (Jacq.) Willd, belonging to the Talinaceae family, is known as bredo, purslane (Agra et al., 2008) and waterleaf (Aja et al., 2010). This species is cultivated on a large scale for food consumption and medicinal purposes in South America (mainly in the North, Northeast, and Midwest regions of Brazil), Asia and Africa (Akachuku & Fawusi, 1995; Agbonon et al., 2010; Brasileiro, 2010).

In Africa, *T. triangulare* is used intensively and concomitantly with allopathic medicines to treat or prevent diseases, by increasing resistance due to its immunostimulant activity (Agbonon et al., 2010; Liang et al., 2011). This plant is also used as a treatment for measles and diabetes, as a laxative (Agra et al., 2008), for topical treatment of wounds by promoting healing because of its emollient mucilaginous leaves (Mors et al., 2000), and to prevent liver diseases and cancer (Liang et al., 2011).

The leaves and stems of *T. triangulare* are rich in nitrogens compounds, including acrylamides and pheophytins, which are associated with the species' nutritional properties (Amorim et al., 2014). Alexandre et al. (2018) observed higher levels of N, P, Ca, S, B and Mn in *T. triangulare* leaves, including crude protein levels greater than 16%, in comparison with the stems and roots.

Flour made from plants with these characteristics have been used to enrich human diets and can be added to various foods and medicinal preparations. They have been found to produce satisfactory results in physicochemical and sensory analyses (Rocha et al., 2008; Martinevski et al., 2013; Almeida et al., 2014; Gusso et al., 2015). Drying is used in the productive process to remove excess water from raw material and thus prolong shelf life and prevent microbial spoilage (Mujumdar et al., 2016). Araújo Filho et al. (2011) reported that the dehydration of plant material can be performed in various ways, including natural drying, drying with heated air circulation by conduction and/or convection, osmotic dehydration, and freeze drying, the last of which involves expensive technology. Drying should performed to reduce the moisture to a suitable level so as to obtain a uniform product, without causing changes in the properties of flour, such as discoloration and other changes in physical appearance, loss of aroma, alterations in texture and reduction of nutritional value (Ali et al., 2014).

Given the above, the aim of this study was to investigate the drying kinetics of *T. triangulare* leaves at different temperatures and assess the physicochemical characteristics, mineral, and centesimal composition, and structural changes in the flour produced.

## Materials and Methods

The plant material was collected in the town of Rio Verde, Goiás state, Brazil (geographical coordinates 17°48'55" S and 50°56'28" W and altitude of 754 m) in October 2014. Botanical identification of *Talinum triangulare* (Jacq.) Willd was carried out and a voucher specimen (HRV 468) was deposited in the herbarium of the Goiano Federal Institute of Education, Science and Technology, Rio Verde campus. Seeds were germinated in polypropylene trays using a commercial substrate. Twenty-one days after sowing, seedlings were transplanted to beds and arranged in an environment under shade (50%) for 176 days.

Leaves were collected, selected, washed in running water and immersed for 10 minutes in a 100 ppm sodium hypochlorite solution and then washed with distilled water. Thereafter, leaves were dried in a forced air oven at temperatures of 50, 60, 70 and 80 °C to constant weight. Moisture content was determined by the gravimetric method, as recommended by ASABE (2010).

The moisture content of the leaves during drying was determined using Equation (1):

$$RX = \frac{X - X_e}{X_i - X_e} \quad (1)$$

where RX is the ratio of moisture content of the product (dimensionless), X is the moisture content of the sample (decimal, d.b.), $X_i$ is the initial moisture content of the sample (decimal, d.b.), and $X_e$ is the equilibrium moisture content of the sample (decimal, d.b.).

Mathematical models (Table 1) obtained by nonlinear regression by the Gauss-Newton method were fitted to the experimental data.

**Table 1**. Mathematical models to predict drying of agricultural products.

| Model designation | Model | Eq. |
|---|---|---|
| $RX = 1 + a \times t + b \times t^2$ | Wang and Singh | (2) |
| $RX = a \times \exp(-k \times t) + (1-a) \times \exp(-k_1 \times t)$ | Verma | (3) |
| $RX = \exp\left(-a - \left(\frac{a + 4 \times b \times t}{2 \times b}\right)^{0.5}\right)$ | Thompson | (4) |
| $RX = \exp(-k \times t^n)$ | Page | (5) |
| $RX = \exp(-k \times t)$ | Newton | (6) |
| $RX = a \times \exp(-k \times t^n) + b \times t$ | Midilli | (7) |
| $RX = a \times \exp(-k \times t) + c$ | Logarithmic | (8) |
| $RX = a \times \exp(-k \times t)$ | Henderson and Pabis | (9) |
| $RX = a \times \exp(-k \times t) + (1-a) \times \exp(-k \times a \times t)$ | Exponential of two terms | (10) |
| $RX = a \times \exp(-k_0 \times t) + b \times \exp(-k_1 \times t)$ | Two terms | (11) |
| $RX = a \times \exp(-k \times t) + (1-a) \times \exp(-k \times b \times t)$ | Diffusion approximation | (12) |

Where t is the drying time (h); k, $k_0$, and $k_1$ are drying constants ($h^{-1}$); and a, b, c and n are the model coefficients.

Models were selected considering the coefficient of determination ($R^2$), relative mean error (RME), and standard deviation of estimate (SE). A RME value less than 10% was one of the criteria for selecting models, according to Mohapatra & Rao (2005):

$$P = \frac{100}{N} \sum \frac{|Y - \hat{Y}|}{Y} \quad (13)$$

$$SE = \sqrt{\sum \frac{\left(Y - \hat{Y}\right)^2}{DF}} \quad (14)$$

where Y is the experimental value, Ŷ is the value estimated by the model, N is the number of experimental observations, and DF is the degrees of freedom (number of experimental observations minus the number of model coefficients).

The liquid diffusion model for flat geometric shape with accuracy of eight terms (Equation 4) was adjusted to the experimental leaf drying data, considering the surface area and volume, according to Equation (15):

$$\begin{aligned} RX &= \frac{X - X_e}{X_i - X_e} = \\ &= \frac{8}{\pi^2} \sum_{n_t=0}^{\infty} \frac{1}{\left(2n_t + 1\right)^2} \exp\left[-\frac{\left(2n_t + 1\right)^2 \times \pi^2 \times D \times t}{4} \times \left(\frac{S}{V}\right)^2\right] \end{aligned} \quad (15)$$

where RX is the ratio of moisture content of the sample (dimensionless), $n_t$ is the number of terms, S is the sample's surface area ($m^2$), and V is the volume ($m^3$).

Surface area (S) of leaves was determined in $m^2$ by integrating the digital image of leaves using the ImageJ software (Souza & Amaral, 2015). In addition, volume was determined according to Equation (16):

$$V = S \times c \quad (16)$$

where c is the leaf thickness (m).

The relationship between the effective diffusion coefficient and temperature elevation of drying air was described by the Arrhenius equation:

$$D = D_0 \times \exp\left(\frac{-E_a}{R \times T_{ab}}\right) \quad (17)$$

where $D_0$ is the pre-exponential factor, $E_a$ is the activation energy (kJ $mol^{-1}$), R is the universal gas constant (8.134 kJ $kmol^{-1}$ $K^{-1}$), and $T_{ab}$ is the absolute temperature (K).

Coefficients of the Arrhenius equation were linearized by log-transformation, as in Equation (18):

$$LnD = LnA - \frac{E_a}{R} \times \frac{1}{T_{ab}} \quad (18)$$

To obtain the flour after the drying process, leaves were ground in a Wiley mill, using a 1 mm sieve. In the assessment of mineral composition, nitrogen (N) was determined in an extract obtained by sulfuric acid digestion by the semi-micro Kjeldahl method. The following nutrients were measured in the extract obtained by nitro-perchloric digestion: phosphorus (P), by the molybdate colorimetric method; potassium (K), by atomic emission spectroscopy; sulfur (S), by sulfate turbidimetry; calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn), by atomic absorption spectrophotometry; and boron (B), by the colorimetric method using azomethine-H after incineration in a muffle oven (Malavolta et al., 1997).

Moisture content was determined by drying leaves in an oven at 105 °C to constant weight and ash fraction by incineration in a muffle oven at 550 °C. Protein fraction was determined by the Kjeldahl (semi-micro) method. Ethereal extract quantification was carried out using Soxhlet extractors. Total carbohydrates were obtained according to Sniffen et al. (1992), defined by Equation (19):

$$TC = 100 - \left(CP + EE + MM\right) \quad (19)$$

where CP is the crude protein (%), EE is the ethereal extract (%), and MM is the mineral matter (%).

Assessments were carried out according to the official method described by AOAC (2005). To analyze the parameters of mineral and centesimal composition, average data were submitted to regression analysis ($p < 0.05$).

For scanning electron microscopy analysis, flour samples were degreased by method 1122 (IUPAC, 1979) and extracted by the Soxhlet method. A JSM–6610/Jeol® scanning electron microscope equipped with an EDS and Thermo Scientific NSS spectral imaging system were used for micrograph acquisition. Samples were coated with an ultrathin layer of gold for SEM analysis, with electron beam emission by a tungsten filament.

Flour samples were also submitted to analysis by using an absorption spectrophotometer in the infrared region (PerkinElmer Frontier UATR), in transmittance mode, with an accumulation of 64 scans per second in the regions between 650 and 4000 $cm^{-1}$.

## Results and Discussion

Table 2 shows the values of coefficient of determination ($R^2$), relative mean error (RME), and estimated mean error (SE) of the adjusted models during the drying process of *T. triangulare* leaves to obtain flour at different temperatures. Coefficients of determination ($R^2$) of the Wang and Singh (2), Page (5) and Midilli (7) models presented values higher than 95% for all drying temperatures. According to Kashaninejad et al. (2007), a coefficient of determination higher than 95% indicates a good representation of results observed by mathematical models.

Regarding the estimated mean error (SE), all models presented low values. However, the Wang and Singh (2), Page (5) and Midilli (7) models had the lowest values for all temperatures. For relative mean error (RME), only the Page (5) and Midilli (7) models presented values lower than 10% for all conditions tested, standing out as the most appropriate models to represent drying phenomenon of *T. triangulare* leaves, as also reported by Simha & Gugalia (2013) for *Spinacia oleracea* and Radunz et al. (2011) for *Baccharis trimera*. Thus, both models showed good adjustments to the experimental

**Table 2.** Coefficients of determination ($R^2$, %), relative mean error (RME, %) and estimated mean error (SE, decimal) for 11 models analyzed during drying of *Talinum triangulare* leaves at temperatures of 50, 60, 70 and 80 °C.

| Model | $R^2$ | SE | RME | $R^2$ | SE | RME |
|---|---|---|---|---|---|---|
| | | 50 °C | | | 60 °C | |
| Wang and Singh | 99.35 | 0.022 | 8.86 | 97.34 | 0.054 | 48.53 |
| Verma | 93.72 | 0.068 | 25.70 | 73.31 | 0.173 | 119.97 |
| Thompson | 77.33 | 0.128 | 47.02 | 73.31 | 0.170 | 118.90 |
| Page | 98.94 | 0.028 | 8.24 | 99.54 | 0.022 | 5.930 |
| Newton | 77.33 | 0.127 | 47.02 | 73.31 | 0.167 | 118.90 |
| Midilli | 99.84 | 0.011 | 4.28 | 99.85 | 0.013 | 6.69 |
| Logarithmic | 91.73 | 0.078 | 22.90 | 92.64 | 0.091 | 26.23 |
| Henderson and Pabis | 82.47 | 0.113 | 41.47 | 80.95 | 0.144 | 98.39 |
| Exponential of two terms | 77.33 | 0.128 | 47.02 | 91.96 | 0.093 | 64.09 |
| Two terms | 82.47 | 0.115 | 41.38 | 76.74 | 0.164 | 128.16 |
| Diffusion approximation | 77.33 | 0.130 | 47.02 | 92.98 | 0.089 | 58.03 |
| | | 70 °C | | | 80 °C | |
| Wang and Singh | 98.32 | 0.041 | 15.00 | 98.25 | 0.036 | 9.01 |
| Verma | 97.54 | 0.050 | 17.41 | 98.53 | 0.034 | 11.36 |
| Thompson | 75.25 | 0.157 | 53.00 | 63.52 | 0.165 | 60.46 |
| Page | 99.58 | 0.020 | 3.79 | 98.28 | 0.036 | 7.99 |
| Newton | 75.25 | 0.154 | 52.99 | 63.52 | 0.162 | 60.47 |
| Midilli | 97.71 | 0.049 | 9.85 | 99.49 | 0.020 | 5.67 |
| Logarithmic | 93.78 | 0.080 | 17.01 | 83.18 | 0.114 | 35.56 |
| Henderson and Pabis | 82.79 | 0.131 | 43.63 | 71.97 | 0.145 | 52.56 |
| Exponential with two terms | 75.25 | 0.157 | 52.99 | 62.18 | 0.168 | 64.65 |
| Two terms | 97.95 | 0.047 | 15.34 | 71.97 | 0.151 | 52.56 |
| Diffusion approximation | 75.25 | 0.159 | 52.99 | 97.78 | 0.042 | 13.93 |

data, and can be recommended to represent the drying of *T. triangulare* leaves. However, we selected the Page model to represent the drying phenomenon of *T. triangulare* leaves due to its simplicity.

Figure 1 shows drying curves of *T. triangulare* leaves, with experimental and estimated values of the ratio of moisture content over time by the Page model. A satisfactory fit was found between model and experimental values obtained during drying of *T. triangulare* leaves. In this context, the required times for attaining a moisture content of 0.0741 ± 0.0068 (decimal, d.b.) were 32.00, 9.86, 7.33 and 6.33 h for drying temperatures of 50, 60, 70 and 80 °C, respectively, showing that an increase in air temperature decreased drying time of *T triangulare* leaves.

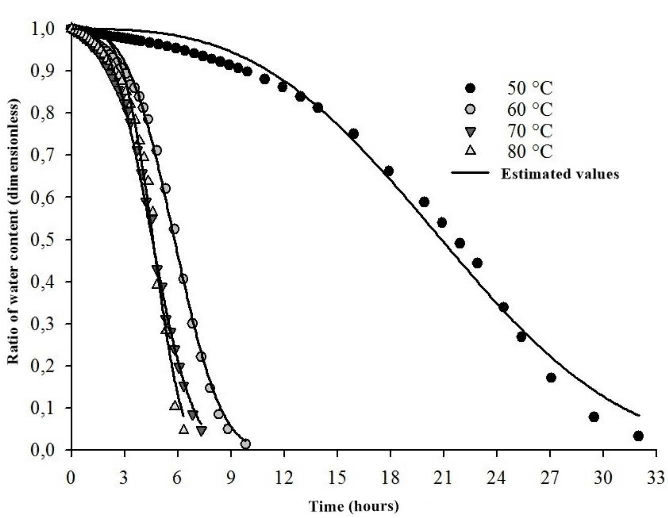


**Figure 1.** Drying kinetics values of *Talinum triangulare* leaves, experimental and estimated by the Page model for temperatures of 50, 60, 70 and 80 °C.

The reduction in drying time with temperature increase is related to the decrease in vapor pressure provided by higher temperatures, which remove water more easily and quickly, as observed by different researchers for several products (Doymaz, 2006; Premi et al., 2010; Oliveira et al., 2013).

The dehydration of plant material reduces the action of enzymes and microbial contamination and increases the levels of active substances in relation to fresh weight. However, the use of higher drying temperature can interfere in the functional activity of the plant material, as observed by Julkunen-Tiitto & Sorsa (2001). They reported the decomposition of flavonoids, tannins and salicylates in *Salix purpurea* leaves submitted to temperatures higher than 60 ºC, with reduction in the concentrations of active compounds between 40 and 79% in relation to fresh leaves. In turn, Negri (2007) reported that the concentration of polyphenols, tannins and flavonoids and the oxidant activity of *Maytenus ilicifolia* leaves were reduced when submitted to drying temperatures above 50 ºC, reaching the highest decomposition when exposed to a temperature of 80 $^{o}$C.

Values of drying constant k and coefficient n of the Page model, adjusted to the experimental data from drying *T. triangulare* leaves at different temperatures, were significant, showing it can be used to represent drying of *T. triangulare* leaves (Table 3). For the Midilli model, only the coefficients k, n, and b were not significant at a temperature of 70 °C.

**Table 3.** Coefficients of Page and Midilli models adjusted for drying of *Talinum triangulare* leaves at temperatures of 50, 60, 70 and 80 °C.

| Coefficient | Temperature (°C) | | | |
|---|---|---|---|---|
| | 50 | 60 | 70 | 80 |
| | | Page | | |
| K | 0.000076** | 0.002288** | 0.008103** | 0.01491** |
| N | 2.99957** | 3.245375** | 2.930891** | 4.025979** |
| | | Midilli | | |
| A | 0.993611** | 0.978601** | 0.903963** | 0.991441** |
| K | 0.000018** | 0.000135** | −0.374474$^{ns}$ | 0.000456** |
| N | 3.318695** | 3.469732** | 0.436144$^{ns}$ | 4.540424** |
| B | −0.005284** | −0.003147** | −0.298944$^{ns}$ | −0.020696** |

**Significant at 1% by the t-test. $^{ns}$ Non-significant by the t-test.

Table 4 shows the values of effective diffusion coefficient, which increased as temperature increased. The activation energy for liquid diffusion in the drying process of *T. triangulare* leaves was 46.724 kJ mol$^{-1}$ for a temperature range between 50 and 80 °C. According to Zogzas et al. (1996), the activation energy for agricultural products ranges from 12.7 to 110 kJ mol$^{-1}$. Thus, the activation energy found in this study is within the range proposed by these authors.

With respect to the mineral composition of flour produced from *T. triangulare* leaves dried at different temperatures, only the levels of N, Mg and Cu were changed. For N and Mg, the response decreased linearly with, reductions of 19.60 and 5.50 mg 100 g$^{-1}$ of dry weight, respectively, for each increase of 1 °C in drying temperature. On the other hand, drying behavior of Cu was explained by a quadratic model, with highest concentration in the flour at a drying temperature of 60 °C (Table 5).

The macronutrients N, P, K, Mg and Ca presented the highest concentrations in *T. triangulare* leaves when compared to measurements reported by Fasuyi (2007). Aremu & Udoessien (1990) found higher concentrations of K (3166 mg 100 g$^{-1}$ of dry weight) and lower concentrations of Ca and Mg (880.5 and 321.5 mg 100 g$^{-1}$ of dry weight, respectively) in leaves of *T. triangulare* dried at 60 ºC. Ifon & Bassir (1979) found lower concentrations of P and higher of K, Ca and Mg (Table 5).

The micronutrients Mn and Fe presented the highest concentrations at all temperatures, demonstrating that *T. triangulare* leaves are rich in these essential nutrients (Table 5). Aremu & Udoessien (1990) reported higher concentrations of Fe and Zn and lower of Cu, in the last case with a concentration near that found by us. The concentration of Fe was similar to that reported by Ifon & Bassir (1979) and Fasuyi (2007). In leaves of *T. triangulare* cultivate in Nigeria, Fasuyi (2007) measured higher Zn concentration than we observed. The concentration of B was close to that found for Zn (Table 5). High levels of Zn, Cu, Mo, Ni and nitrate in plants can be toxic to humans. On the other hand, it is important to increase the concentration of essential nutrients in the edible parts of plants, while at the same time reducing, or at least keeping in a safe range, the concentrations of toxic or undesirable elements (Wang et al., 2008).

The daily nutrient intakes recommended for adults according to Board Resolution 269 from ANVISA (Brasil, 2015) are shown in Table 5 and can be met depending on the amount of nutrient ingested. For instance, when ingesting 100 g of *T. triangulare* flour, these recommendations can be met, except for P. However, excess fibers and some anti-nutritional factors can decrease nutritional value, as observed by Leite et al. (2009) in *Talinum fruticosum*.

For centesimal composition, no changes were observed due to increased drying temperature for the assessed parameters, which presented average values of 7.30% for moisture content, 0.3% for ashes, 19% for protein, 7% for ethereal extract and 73% for total carbohydrates (Table 6).

**Table 4.** Average values of diffusion coefficient (m$^2$ s$^{-1}$) obtained for *Talinum triangulare* leaves dried at temperatures of 50, 60, 70 and 80 °C.

| Coefficient | Temperature (°C) | | | | Equation | $R^2$ |
|---|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | | (%) |
| D | $0.484\times10^{-12}$ | $1.87\times10^{-12}$ | $1.89\times10^{-12}$ | $2.44\times10^{-12}$ | $D = 2.2\times10^{-12} + 5.9\times10^{-14}\,T$ | 82.89 |

**Table 5.** Mineral concentrations (mg 100 g$^{-1}$ of dry weight) of flour samples made from of *Talinum triangulare* leaves after drying at different temperatures compared to the literature and with recommended daily intake values for adults according to ANVISA.

| Nutrient | Temperature °C | | | | Average or adjusted equation | Reference | | | RDI* (mg) Brasil (2015) |
|---|---|---|---|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | | (1) | (2) | (3) | |
| N | 2800 | 2800 | 2520 | 2240 | $\hat{Y} = 3864 - 19.60\,x$; $R^2 = 89.09$ | 1970 | - | - | - |
| P | 580 | 550 | 560 | 580 | $\hat{Y} = \bar{Y} = 567.50$ | 77 | - | 340 | 700 |
| K | 2700 | 2500 | 2350 | 2900 | $\hat{Y} = \bar{Y} = 2612.50$ | 270 | 3166 | 6100 | - |
| S | 190 | 130 | 190 | 220 | $\hat{Y} = \bar{Y} = 182.50$ | - | - | 230 | - |
| Ca | 1480 | 1110 | 1400 | 1450 | $\hat{Y} = \bar{Y} = 1360$ | 80 | 880.50 | 2400 | 1000 |
| Mg | 1060 | 980 | 1030 | 860 | $\hat{Y} = 1340 - 5.50\,x$; $R^2 = 64.98$ | 70 | 321.50 | 2200 | 260 |
| Cu | 2.32 | 3.18 | 3.06 | 2.21 | $\hat{Y} = -14.54 + 0.551\,x - 0.0043\,x^2$; $R^2 = 99.58$ | - | 3.31 | 1 | 0.9 |
| Fe | 37.25 | 31.73 | 50.41 | 46.25 | $\hat{Y} = \bar{Y} = 41.41$ | 39.20 | 26.40 | 41 | 14 |
| Mn | 46.27 | 46.2 | 43.25 | 42.99 | $\hat{Y} = \bar{Y} = 44.68$ | - | 5.62 | 35 | 2.3 |
| Zn | 11.06 | 12.33 | 16.67 | 14.6 | $\hat{Y} = \bar{Y} = 13.66$ | 50 | 28.93 | 9.30 | 7 |
| B | 9.96 | 9.96 | 10.99 | 10.99 | $\hat{Y} = \bar{Y} = 10.47$ | - | - | - | - |

*RDI: recommended daily intake for adults. (1) Fasuyi (2007); (2) Aremu & Udoessien (1990); (3) Ifon & Bassir (1979).

Similar results were obtained for *T. triangulare* leaves by Alexandre et al. (2018), who reported average values of 0.36% for ashes, 16.6% for crude protein, 5.37% for ethereal extract, and 77.6% for total carbohydrates, after drying at 65 °C for 72 hours. However, Ifon & Bassir (1980), evaluating the nutritional value of leafy green vegetables in Nigeria, found different values in *T. triangulare* for ashes (18%) and total carbohydrates (53%) and similar values for crude protein (22%) and lipids (5%).

As can be seen in Figure 2, electron micrographs showed that the flour samples obtained at different temperatures

**Table 6.** Average values of moisture content (%), ashes (%), total protein (%), ethereal extract (%), and total carbohydrates (%) of flour made from *Talinum triangulare* leaves after drying at different temperatures.

| Variable | Temperature (°C) | | | | Average |
|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | |
| Moisture content* (%) | 7.58 | 7.64 | 6.71 | 7.28 | $\hat{Y} = \bar{Y} = 7.30$ |
| Ashes (%) | 0.38 | 0.39 | 0.38 | 0.38 | $\hat{Y} = \bar{Y} = 0.38$ |
| Protein (%) | 19.01 | 18.27 | 18.85 | 19.79 | $\hat{Y} = \bar{Y} = 18.98$ |
| Ethereal extract (%) | 5.16 | 5.10 | 9.98 | 8.08 | $\hat{Y} = \bar{Y} = 7.08$ |
| Total carbohydrates (%) | 75.45 | 76.24 | 70.79 | 71.75 | $\hat{Y} = \bar{Y} = 73.58$ |

*Results expressed on a dry basis.

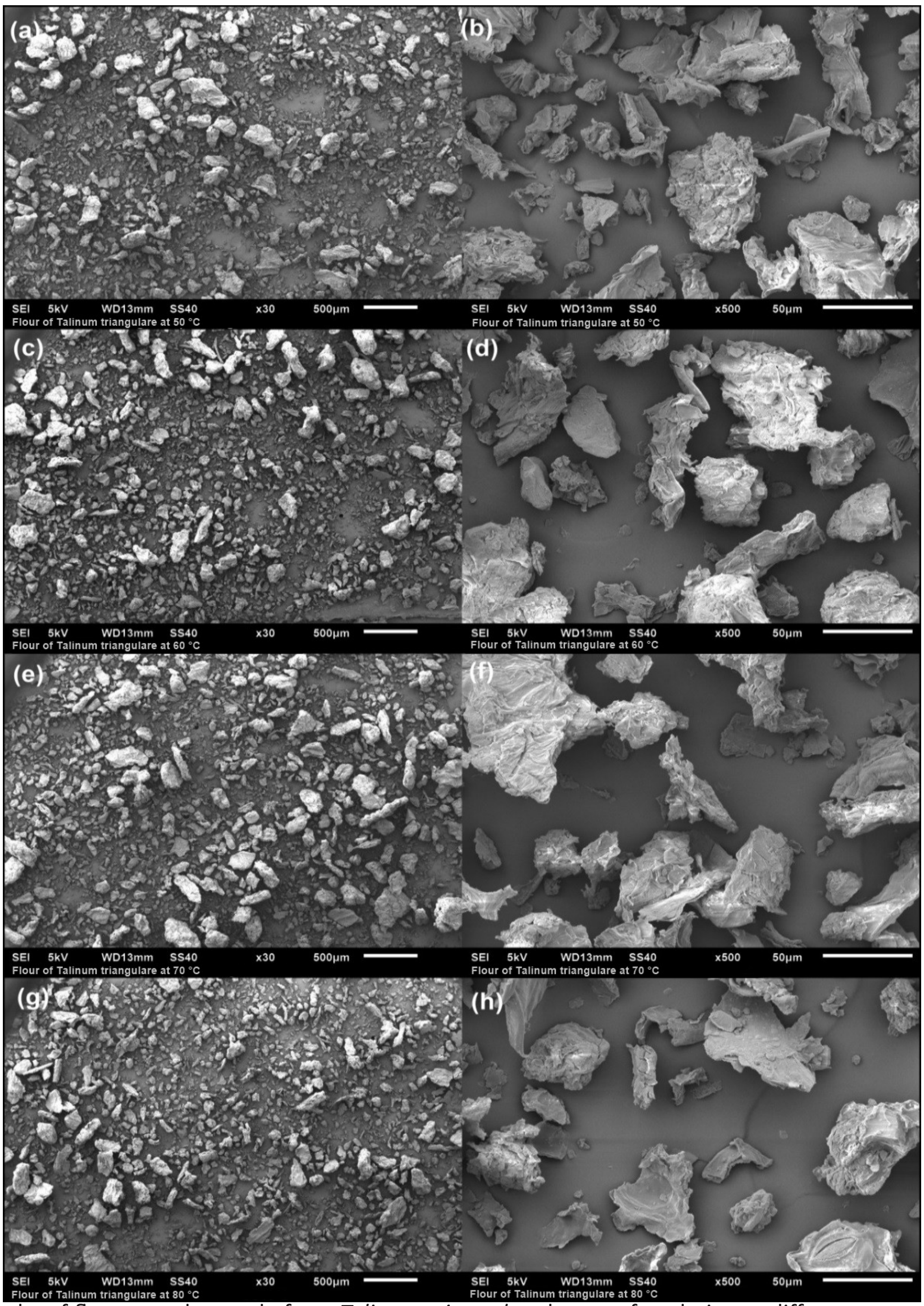


**Figure 2.** Micrographs of flour samples made from *Talinum triangulare* leaves after drying at different temperatures. Scanning electron microscopy under magnification of 30x (left) and 500x (right): (a) and (b), 50 °C; (C) and (d), 60 °C; (e) and (f), 70 °C; and (g) and (h), 80 °C.

had fragments with irregular shapes and dimensions at all temperatures. In addition, no ordered structures were observed, showing no difference between different dry temperatures.

The infrared technique indicated no changes in chemical structure due to the drying of *T. triangulare* leaves (Figure 3). Spectra obtained from the infrared region showed that drying temperatures were not high enough to cause structural or compositional changes in the flour samples. This is a positive characteristic since all samples were resistant to high drying temperatures (50, 60, 70 and 80 °C).

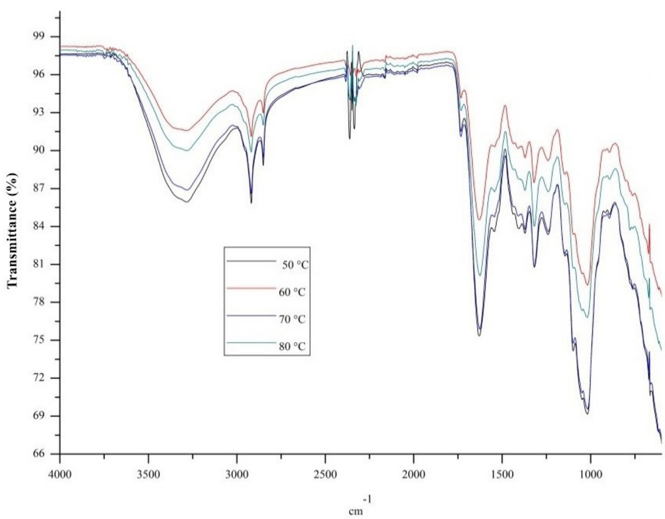


**Figure 3.** Absorption spectra in the infrared region of flour made from *Talinum triangulare* leaves after drying at temperatures of 50, 60, 70 and 80 °C.

## Conclusions

The Page and Midilli models adequately represent the drying of *T. triangulare* leaves. However, the Page model was selected for its greater simplicity. Drying at a temperature of 80 °C reduces the drying time of leaves. Drying at the studied temperatures caused changes in flour samples related to N, Mg and Cu contents, indicating that higher temperatures can affect the functional activity of the plant material. Other variables of mineral, centesimal and structural composition were not modified. Flour made from *T. triangulare* leaves is rich in minerals, especially Fe and Mg.

## Literature Cited

Agbonon, A.; Eklu-Gadegbeku, K.; Aklikokou, K.; Gbeassor, M.; Akpagana, K.; Tam, T.W., Arnason, J.T.; Foster, B.C. In vitro inhibitory effect of West African medicinal and food plants on human cytochrome P450 3A subfamily. Journal of Ethnopharmacology, v.28, n.2, p.390-394, 2010. https://doi.org/10.1016/j.jep.2010.01.039.

Agra, M.D.F.; Silva, K.N.; Basílio, I.J.L.D.; Freitas, P.F.D.; Barbosa-Filho, J.M. Survey of medicinal plants used in the region Northeast of Brazil. Revista Brasileira de Farmacognosia, v.18, n.3, p.42-50, 2008. https://doi.org/10.1590/S0102-695X2008000300023.

Aja, P.M.; Okaka, A.N.C.; Onu, P.N.; Ibiam, U.; Urako, A.J. Phytochemical composition of *Talinum triangulare* (water leaf) leaves. Pakistan Journal Nutrition, v.9, n.6, p.527-530, 2010. https://www.researchgate.net/profile/Udu_Ibiam/publication/49965807_Phytochemical_Composition_of_Talinum_triangulare_Water_Leaf_Leaves/links/02bfe5136c82f312e6000000.pdf. 10 Aug. 2017.

Akachuku, C.O.; Fawusi, M.O.A. Growth characteristics, yield and nutritive value of waterleaf, *Talinum triangulare* (Jacq.) Wild in a semi-wild environment. Discovery and Innovation, v.7, n.2, p.163-172, 1995.

Alexandre, E.C.F.; Andrade, J.W.S; Jakelaitis, A.; Pereira, L.S.; Sousa, G.D.; Oliveira, G.S. Composição mineral e bromatológica de *Talinum triangulare* (Jacq.) Willd cultivada sob sombreamento. Revista Brasileira de Agropecuária Sustentável, v.8, n.2, p.40-51, 2018. https://doi.org/10.21206/rbas.v8i2.491.

Ali, M.A.; Yusof, Y.A.; Chin, N.L.; Ibrahim, M.N.; Basra, S.M.A. Drying kinetics and colour analysis of *Moringa oleifera* leaves. Agriculture and Agricultural Science Procedia, v.2, p.394-400, 2014. https://doi.org/10.1016/j.aaspro.2014.11.055.

Almeida, M.E.F.; Junqueira, A.M.B.; Simão, A.A.; Corrêa, A.D. Caracterização química das hortaliças não-convencionais conhecidas como ora-pro-nobis. Bioscience Journal, v.30, n.3, p.431-439, 2014. http://www.seer.ufu.br/index.php/biosciencejournal/article/view/17555/14557. 10 Aug. 2017.

American Society of Agricultural and Biological Engineers - ASABE. Moisture measurement - forages: Standard S358.2 DEC1988, R2008. In: American Society of Agricultural and Biological Engineers (Ed.). Standards, engineering practices, and data. St. Joseph: ASABE, 2010. p.684-685.

Amorim, A.P.O.; Carvalho Junior, A.R.; Lopes, N.P.; Castro, R.N.; Oliveira, M.C.C.; Carvalho, M.G. Chemical compounds isolated from *Talinum triangulare* (Portulacaceae). Food Chemistry, v.160, p.204-208, 2014. https://doi.org/10.1016/j.foodchem.2014.01.114.

Araújo Filho, D.G.; Eidam, T.; Borsato, A.V.; Raupp, D.S. Processamento de produto farináceo a partir de beterrabas submetidas à secagem estacionária. Acta Scientiarum Agronomy, v.33, n.2, p.207-214, 2011. https://doi.org/10.4025/actasciagron.v33i2.4885.

Aremu, C.Y.; Udoessien, E.I. Chemical estimation of some inorganic elements in selected tropical fruits and vegetables. Food Chemistry, v.37, n.3, p.229-234, 1990. https://doi.org/10.1016/0308-8146(90)90140-Y.

Association of Official Analytical Chemists - International - AOAC. Official methods of analysis. 18ed., Gaithersburg: AOAC, 2005. 1298p.

Brasil. Ministério da Saúde. Agência Nacional de Vigilância Sanitária – ANVISA. Resolução de Diretoria Colegiada - RDC n. 269, de 22 de setembro de 2005. Aprova o Regulamento técnico sobre a ingestão diária recomendada (IDR) de proteína, vitaminas e minerais. http://portal.anvisa.gov.br/documents/33916/394219/RDC_269_2005.pdf/2e95553c-a482-45c3-bdd1-f96162d607b3. 16 Sep. 2017.

Brasileiro, B.G. Germinação e produção de compostos fenólicos em plantas de *Talinum triangulare* (Jacq.) Wild (Portulacaeae) tratadas com homeopatia. Viçosa: Universidade Federal de Viçosa, 2010. 123p. Tese Doutorado. http://locus.ufv.br/handle/123456789/1130. 22 Sep. 2017.

Doymaz, I. Thin-layer drying behavior of mint leaves. Journal of Food Engineering, v.74, n.3, p.370-375, 2006. https://doi.org/10.1016/j.jfoodeng.2005.03.009.

Fasuyi, A.O. Bio-nutritional evaluations of three tropical leaf vegetables (*Telfairia occidentalis, Amaranthus cruentus* and *Talinum triangulare*) as sole dietary protein sources in rat assay. Food Chemistry, v.103, n.3, p.757-765, 2007. https://doi.org/10.1016/j.foodchem.2006.09.030.

Gusso, A.P.; Mattanna, P.; Richards, N. Yacon: benefícios à saúde e aplicações tecnológicas. Ciência Rural, v.45, n.5, p.912-919, 2015. https://doi.org/10.1590/0103-8478cr20140963.

Ifon, E.T.; Bassir, O. The nutritive value of some Nigerian leafy green vegetables - Part 1: Vitamin and mineral contents. Food Chemistry, v.4, n.4, p.263-26, 1979. https://doi.org/10.1016/0308-8146(79)90014-1.

Ifon, E.T.; Bassir, O. The nutritive value of some Nigerian leafy green vegetables - Part 2: The distribution of protein, carbohydrates (including ethanol-soluble simple sugars), crude fat, fibre and ash. Food Chemistry, v.5, n.3, p.231-235, 1980. https://doi.org/10.1016/0308-8146(80)90014-X.

International Union of Pure and Applied Chemistry - IUPAC. Standard methods for the analysis of oils, fats and derivatives. 6.ed. Oxford: Pergamon Press, 1979. 138p.

Julkunen-Tiitto, R.; Sorsa, S. Testing the effects of drying methods on willow flavonoids tannins and salicylates. Journal of Chemical Ecology, v.27, n.4, p.779-789, 2001. Available at: https://doi.org/10.1023/A:1010358120482.

Kashaninejad, M.; Mortazavi, A.; Safekordi, A.; Tabil, L.G. Thin-layer drying characteristics and modeling of pistachio nuts. Journal of Food Engineering, v.78, n.1, p.98-108, 2007. https://doi.org/10.1016/j.jfoodeng.2005.09.007.

Leite, J.F.M.; Silva, J.A.D.; Gadelha, T.S.; Gadelha, C.A.; Júnior, S. Nutritional value and antinutritional factors of foliaceous vegetable *Talinum fruticosum*. Revista do Instituto Adolfo Lutz, v.68, n.3, p.341-345, 2009. http://periodicos.ses.sp.bvs.br/pdf/rial/v68n3/v68n3a03.pdf. 15 Sep. 2015.

Liang, D.; Zhou, Q.; Gong, W.; Wang, Y.; Nie, Z.; He, H.; Zhang, J. Studies on the antioxidant and hepatoprotective activities of polysaccharides from *Talinum triangulare*. Journal of Ethnopharmacology, v.136, n.2, p.316-321, 2011. https://doi.org/10.1016/j.jep.2011.04.047.

Malavolta, E.; Vitti, G.C.; Oliveira, S.A. Avaliação do estado nutricional das plantas. Piracicaba: Potafos, 1997. 319p.

Martinevski, C.S; Oliveira, V.R.; Rios, A.O.; Flores, S.H.; Venzke, J.G. Utilização de bertalha (*Anredera cordifolia* (Ten.) Steenis) e ora-pro-nobis (*Pereskia aculeata* Mill.) na elaboração de pães. Brazilian Journal of Food Nutrition, v.24, n.3, p.1-6, 2013.

Mohapatra, D.; Rao, P.S. A thin layer drying model of parboiled wheat. Journal of Food Engineering, v. 66, n.4, p.513-518, 2005. https://doi.org/10.1016/j.jfoodeng.2004.04.023.

Mors, W.B.; Rizzini, C.T.; Pereira, N.A. Medicals plants of Brazil. 6.ed. Algonac: Michigan Reference Publications, 2000. 501p.

Mujumdar, A.S.; Law, C.L.; Woo, M.W. Freeze drying: effects on sensory and nutritional properties. In: Caballero, B.; Finglas, P.M.; Toldra, F. In: Encyclopedia of Food and Health. Waltham: Academic Press, 2016. p.99-103. https://doi.org/10.1016/B978-0-12-384947-2.00327-5.

Negri, M.L.S. Secagem das folhas de espinheira-santa – *Maytenus ilicifolia* Mart. ex Reis. sob diferentes temperaturas e influência nos teores de polifenóis, na atividade antioxidante e nos aspectos microbiológicos. Curitiba: Universidade Federal do Paraná, 2007. 79p. Dissertação Mestrado. http://hdl.handle.net/1884/12096. 10 Sep. 2017.

Oliveira, D.E.C.; Resende, O.; Montes, A.L.; Silva, F.G. Drying kinetics of *Aristolochia cymbifera* Mart. and Zucc. leaves. African Journal of Agricultural Research, v.8, n.10, p.922-929, 2013. https://doi.org/10.5897/AJAR12.1607.

Premi, M.; Sharma, H.K.; Sarkar, B.C.; Singh, C. Kinetics of drumstick leaves (*Moringa oleifera*) during convective drying. African Journal of Plant Science, v.4, n.10, p.391-400, 2010. http://www.academicjournals.org/journal/AJPS/article-full-text-pdf/DB5027812026. 15 Aug. 2018.

Radünz, L.L.; Amaral, A.S.; Mossi, A.J.; Melo, E.C.; Rocha, R.P. Avaliação da cinética de secagem de carqueja. Engenharia na Agricultura, v.19, n.1, p.19-27, 2011. https://doi.org/10.13083/reveng.v19i1.147.

Rocha, D.R.C.; Pereira Júnior, G.A.; Vieira, G.; Pantoja, L.; Santos, A.S.; Pinto, N.A.V.D. Macarrão adicionado de ora-pro-nóbis (*Pereskia aculeata* miller) desidratado. Alimentos e Nutrição, v.19, n.4, p.559-465, 2008. http://serv-bib.fcfar.unesp.br/seer/index.php/alimentos/article/viewFile/656/552. 10 Aug. 2017.

Simha, P.; Gugalia, A. Thin layer drying kinetics and modelling of *Spinacia oleracea* leaves. International Journal of Applied Engineering Research, v.8, n.9, p.1053-1066, 2013. https://www.ripublication.com/Volume/ijaerv8n9.htm. 10 Aug. 2018.

Sniffen, C.J.; O'Connor, J.D.; Van Soest, P.J.; Fox, D.G.; Russell, J.B. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. Journal of Animal Science v.70, n.11, p.3562-3577, 1992. https://doi.org/10.2527/1992.70113562x.

Souza, M.C.; Amaral, C.L. Modelo linear não-destrutivo para estimativa de área foliar de *Vernonia ferruginea* Less. Brazilian Journal of Biology, v.75, n.1, p.152-156, 2015. https://doi.org/10.1590/1519-6984.09813.

Wang, Z.H.; Li, S.X.; Malhi, S. Effects of fertilization and other agronomic measures on nutritional quality of crops. Journal of the Science of Food and Agriculture, v.88, n.1, p.7-23, 2008. https://doi.org/10.1002/jsfa.3084.

Zogzas, N.P.; Maroulis, Z.B.; Marinos-Kouris, D. Moisture diffusivity data compilation in foodstuffs. Drying Technology, v.14, n.10, p.2225-2253, 1996. https://doi.org/10.1080/07373939608917205.